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A BRIEF SUMMARY OF BIOLOGICAL SOUND SCATTERING IN THE OCEAN.(U)

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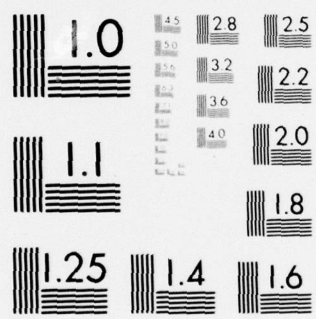

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(6) A BRIEF SUMMARY OF BIOLOGICAL SOUND SCATTERING IN THE OCEAN.

TRACOR, INC Austin (11) August, 1970 (12) 17p.

A Brief History

The history of biological sound scattering in the ocean is only about thirty years old. Personnel from UCDWR in San Diego were among the first to observe and report the existance of scattering layers of unknown origin between San Diego and Guadalupe Island in the early 1940's. Among the earliest plausible explanations offered for the observed scattering anomalies was scattering from "concentration of fish, bubbles or plankton."[1] In these early measurements, three scattering layers were noted at depths of 100 feet, 600 feet and 1000 feet. In the mid-1940's, the phenomenon of vertical migration of the deep scattering layer (DSL) was observed. This phenomenon is characterized by a rapid ascent of the DSL at sunset and a rapid desent at sunrise. The observation of this behavior strengthened the arguments which favored biological causes as explanations for the DSL.

Figure 1 illustrates the results of one of the early experiments carried out at UCDWR. The peak at A is the DSL and is roughly 20 dB above normal volume reverberation levels. Other records from the same experiments show multiple layering.

The diurnal vertical migration in depth of the DSL is illustrated in Figure 2.

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Reinforced with the observation of diurnal migration, the scientific community set out to catch the cause of the DSL

1 Physics of Sound in the Sea, Part II, Reverberation. NDRC, Summary Technical Report, Div. 6, Vol. 7, 1946.

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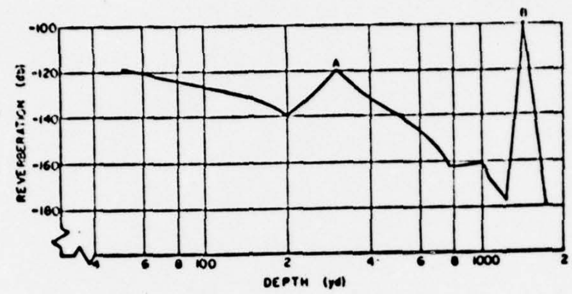

Figure 1 REVERBERATION FROM THE DEEP SCATTERING LAYER (Reproduced from NDRC, Summary Technical Report, Div. 6, Vol. 7, 1946.)

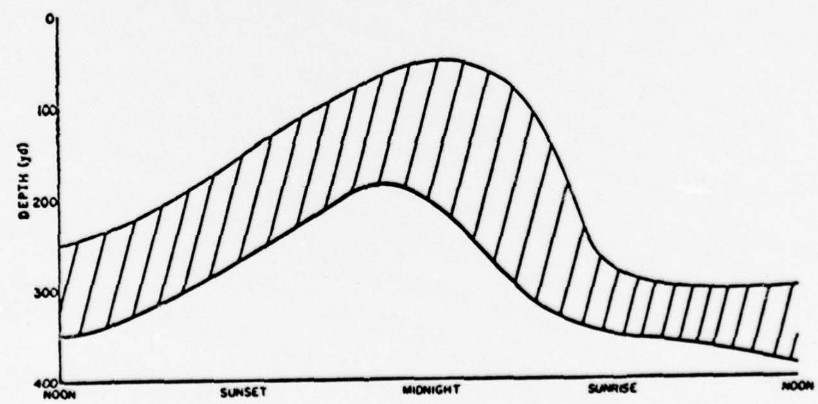

Figure 2 DIURNAL VARIATION IN DEPTH OF THE DEEP SCATTERING LAYER (Reproduced from NDRC, Summary Technical Report, Div. 6, Vol. 7, 1946.)

in the act of scattering sound. Numerous net hauls through the DSL as observed on echo sounding gear at a large number of frequencies between 20 kHz and 100 kHz were disappointingly negative, yielding only small numbers of very small biological species. Attempts to photograph the mechanism causing the DSL met with similar results.

Efforts in the early 1950's concentrated on better instrumentation, better measurements and more "negative" net hauls and "negative" attempts at direct observation. One of the more notable investigations into the DSL was carried out in 1950-53 by V. Anderson at the Scripps Institution of Oceanography. A brief summary of this work is given in the following excerpt from the Underwater Acoustics Handbook by Albers.[1]

> A new technique for studying scattering within the deep-scattering layer has been developed at the Scripps Institution of Oceanography of the University of California by V. C. Anderson. In this method, which is described in SIO Report, 53-56, published in 1953, both the projector and the receiver are located directly in the deep-scattering layer to investigate the sound received by the hydrophone from nearby organisms that are irradiated by pulses of sound generated by a high-intensity, broad-band source. As his source of sound, Anderson used an underwater spark produced by the breakdown between two copper electrodes through a hole in a mica disc.
>
> Anderson claims the following advantages for this method of observation:

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1 Albers, Vernon M., Underwater Acoustics Handbook, Penn State University Press, 1965.

(1) "The intensity of the scattered sound in higher for the same intensity source because of the shorter range.

(2) "Non-directional transducers may be used since only local scattering is to be observed. With the non-directional transducer, the geometry is independent of frequency, and the intensity of the scattered return does not depend on the angular position of the scatterer, which is indeterminate, but is a function of only the range and the acoustic cross section.

(3) "The volume of ocean observed at one time is drastically reduced, permitting the resolution of individual scatterers.

(4) "If a sound pulse having a broad energy spectrum is used, the frequency dependence of the acoustic cross section for individual scatterers or groups of scatterers may be determined by comparison of the energy spectrum of the outgoing pulse with that of the scattered sound."

This technique is still in use at MPL with some modifications which include replacement of the "sparker" source with transducers and the addition of on-line data processing facilities. Anderson also showed, theoretically, that the physical cross section would have to be about ten times larger than the acoustic cross section down to 2 Kc if the scattering organisms were assumed to be fluid spheres. It was also shown that the dependence of the measured acoustic cross section on frequency can be explained by the assumption of scattering organisms with air-filled swim bladders.

Albers[1] also states that:

> The results of the studies made by Anderson's method in the deep-scattering layer indicate that the marine organisms have swim bladders and that their average physical cross section is of the order of 0.01 to 0.04 square yard. The density of the scatterers is about one scatterer per 1000 cubic yards.

After Dr. Anderson's work the overall status of the DSL remained relatively static until the early 1960's. There was a relatively high confidence that the DSL was of biological origin, but no direct evidence. In 1962-63 two papers[2,3] on the acoustic cross section of single fish appeared. These papers were mostly notable because there was no other data of this nature available. Little more exists today. Both papers have severe cases of "extrapolation." Two additional investigators in this area were Anderson, who worked with goldfish, and Volberg, who experimented with tuna.

A summary of the available data on the target strength of single fish as a function of frequency is given in Figures 3, 4 and 5.

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1 Ibid.

2 Haslett, R. G. W., "Determination of the Acoustic Backscattering Patterns and Cross-Sections of Fish," British Journal of Applied Physics, 13:349 (1962).

3 Cushing, D. H., Jones, F. R. Harden, Mitson, R. B., Ellis, G. H., and Pearce, G., "Measurements of the Target Strength of Fish," Journal of the British Institute of Radio Engineers, 25:299 (1963).

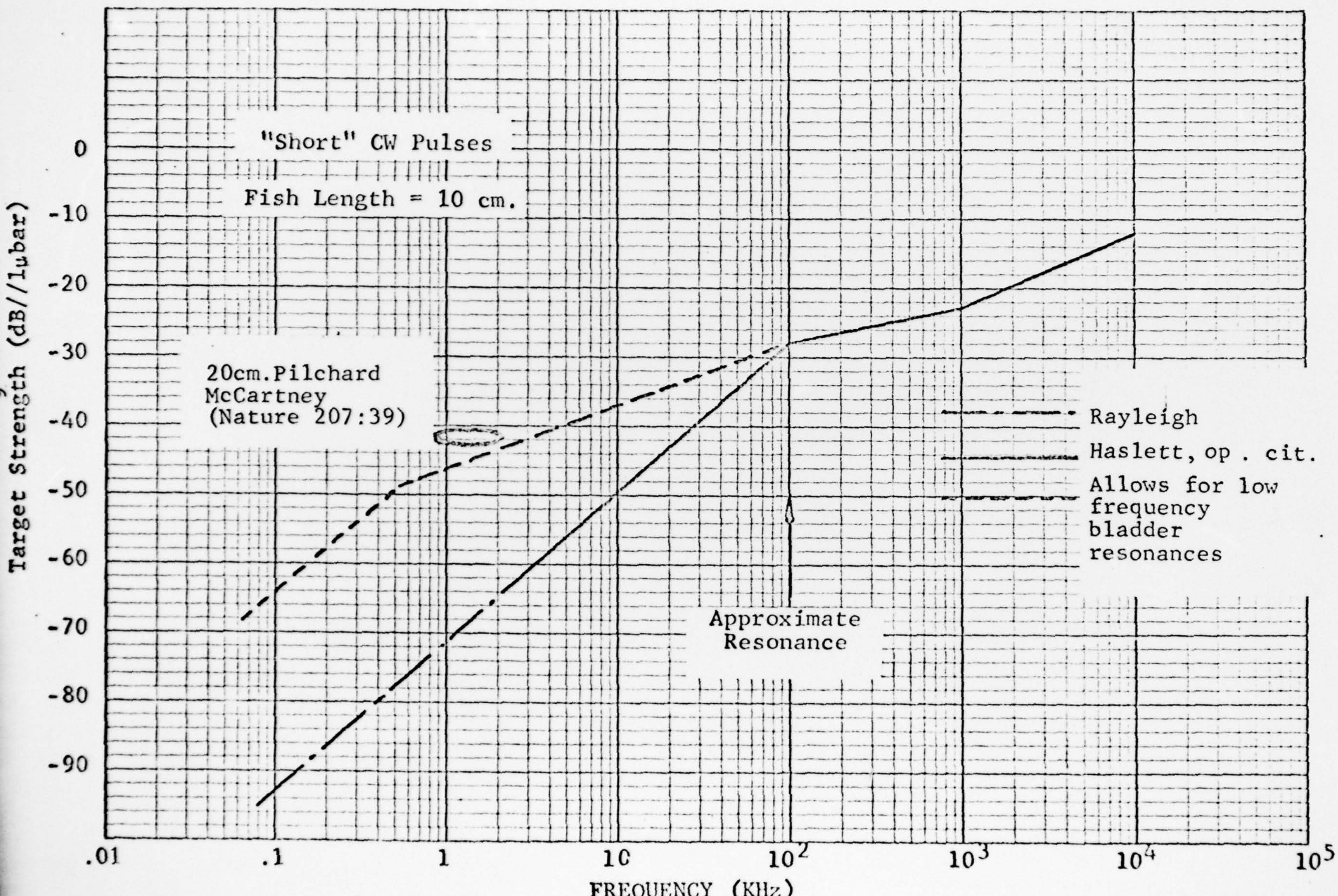

FIGURE 3 Target Strength vs. Frequency

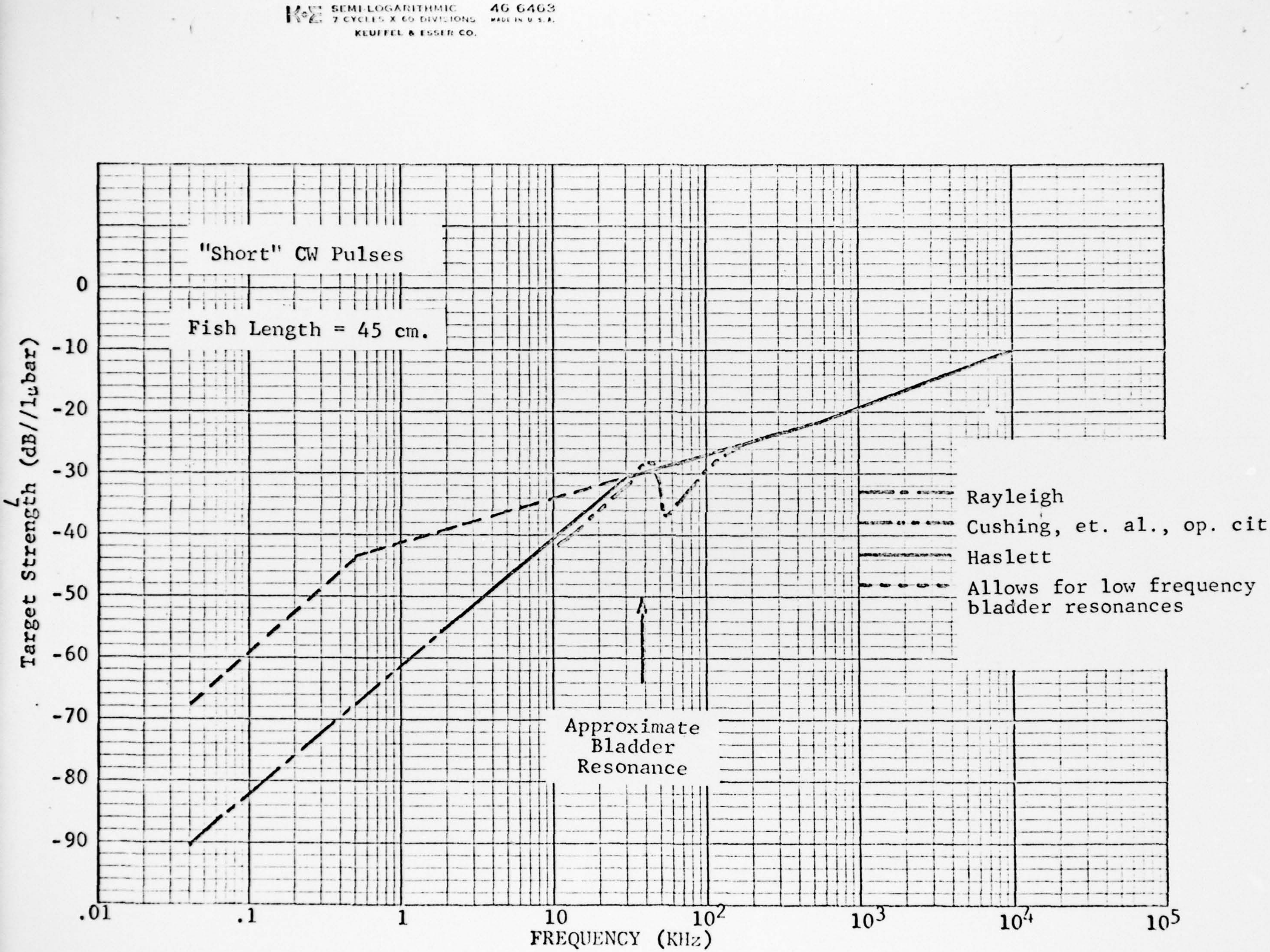

FIGURE 4 Target Strength vs. Frequency

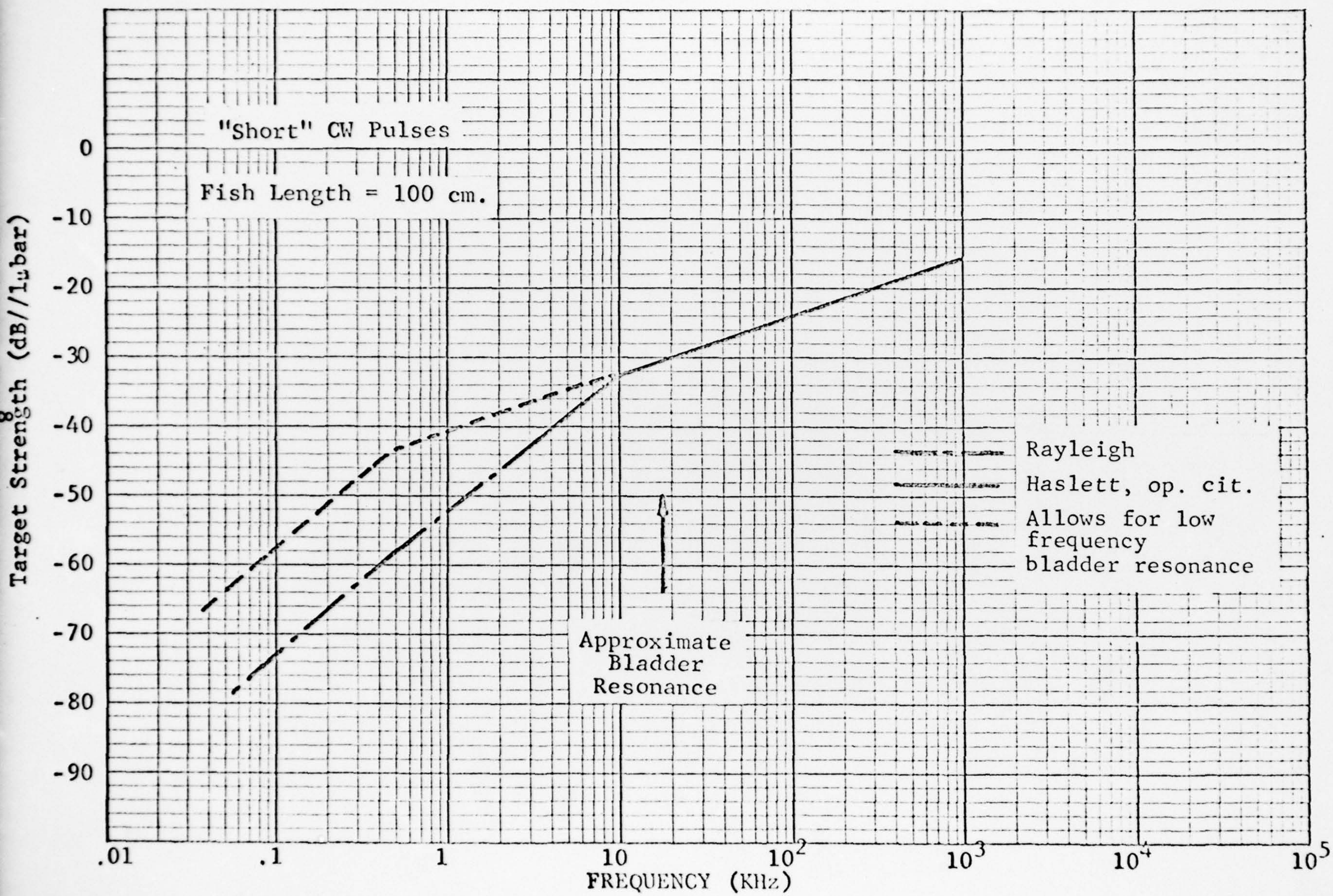

FIGURE 5 Target Strength vs. Frequency

Marshall and Chapman[1] added evidence for a frequency selective mechanism in the DSL in 1964. This reinforced the work done by Anderson in about 1952 and that by Hersey and Backus[2] in 1962.

A very significant paper was published in 1964 by I. B. Andreeva[3]. Andreeva measured the acoustic scattering strength of the DSL as a function of frequency. The layer was then fished with a trawl net resulting in a catch of about 600 fish. The bladder size of each fish was measured and the weighted bladder resonant frequency plotted against frequency along with the acoustic scattering cross section. The result is shown in Figure 3. Note that the biological curve is displaced in frequency from the acoustic curve. This is explained by the decreasing efficiency of trawl netting for larger, faster fish. This was the first direct evidence of the relation between the DSL and bathypelagic/mezopelagic fishes with swim bladders.

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1 Marshall, J. R. and Chapman, R. P., "Reverberation From a Deep Scattering Layer Measured with Explosive Sound Sources," JASA 36:164 (1964).

2 Hersey, J. B., Backus, R. H. and Hellwig, J., "Sound-Scattering Spectra of the Deep Scattering Layers in the Western North Atlantic Ocean," Deep Sea Research 8:196 (1962).

3 Andreeva, I. B., "Scattering of Sound by Air Bladders of Fish in Deep-Sound Scattering Ocean Layers," Soviet Physics - Acoustics 10:17 (1964).

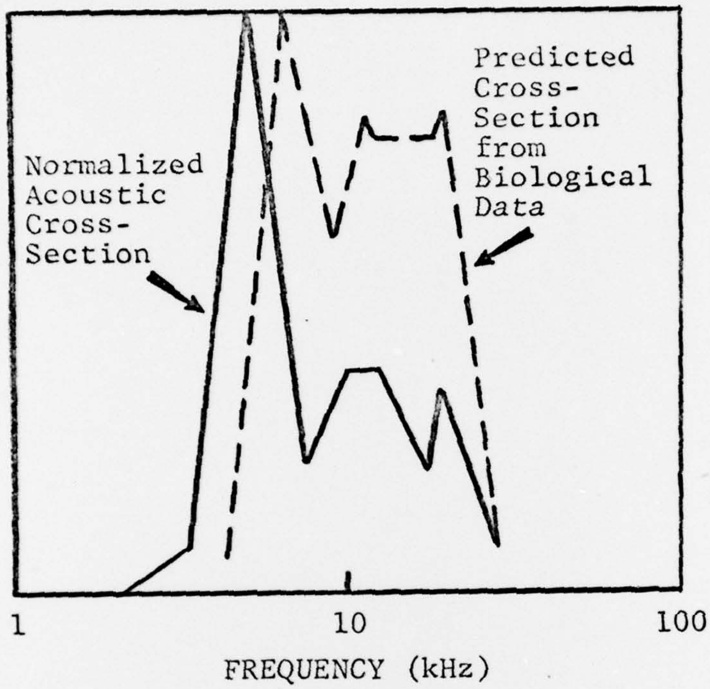

Figure 3 RELATION OF ACOUSTIC AND BIOLOGICAL CROSS SECTIONS (Reproduced from "Scattering of Sound by Air Bladders of Fish in Deep-Sound Scattering Ocean Layers," by I. B. Andreeva, Soviet Physics-Acoustics 10:17 (1964).)

In March 1970, an international symposium was held on biological sound scattering in the ocean. This symposium, under the sponsorship of the Maury Center for Ocean Science, Washington, D. C., was attended by about 25 biologists and an equal number of acousticians representing the United States, England, Canada, France and Germany. A list of the papers presented at this meeting will be found in Appendix A. Rather than summarizing the content of each paper, a series of reasonably well accepted facts are presented next which are considered adequate for the purposes of this survey, if one recognizes the dangers inherent in any generalization of this kind. Finally, several areas of current controversy are also indicated.

GENERAL FACTS ABOUT THE DSL

1. The DSL is of biological origin--specifically with principal contributions from bathypelagic and mezopelagic fishes with swim bladders.

2. The density of fish required for a strong DSL ranges between 5 to 18 - 1 mm diameter shelled terapods per square meter at a pycnocline in the Arctic to 1 individual/$10^6 m^3$ in the deep ocean.

3. The low density of scatterers accounts for the "negative" net hauls of previous years. Sampling was inadequate and people were looking for big fish.

4. Vertical migration has been confirmed by trawl catches independent of acoustic observations.

5. Not all DSL's migrate and not all members of the same DSL migrate. This is partially explained by biological evidence of intermixing of midwater communities.

6. Marked changes in the character, frequency, depth and number of DSL's are observed at ecological boundaries for different species.

7. The vertical migrations follow isolunes very closely.

8. Visual observations of DSL's have been made from deep submersibles. In some cases, separation of layers will occur when there is only one constituent species.

9. There are at least two mechanisms operating in swim bladders of fish which migrate: a) constant volume, and b) constant pressure.

10. There is a correlation between bladder size and fish size.

11. The presence of swim bladder fish can significantly affect the absorption of low frequency sound in shallow water.

AREAS OF CONTROVERSY REGARDING THE DSL

1. The phenomenon of vertical migration is unexplained. Vertical migration requires considerable expenditure of energy in terms of bladder control as well as mechanical work. Feeding has not been ruled out but examination of gut contents of trawl catches does not support feeding as a cause.

2. Some members of the same species of vertically migrating organisms migrate on a given day while others do not. Why?

3. Can we use current measurements of the scattering strengths and volumes of the DSL as a valid estimator for the biomass of the world's oceans.

APPENDIX A

1. "Midwater Communities of Deep-Sea Animals"

   Alfred W. Ebeling, University of California
   Santa Barbara, California

2. "The Distribution of Mesopelagic Fishes in the Equatorial and Western North Atlantic Ocean"

   Richard H. Backus, James E. Craddock, Richard L. Haedrich and David L. Shores
   Woods Hole Oceanographic Institution
   Woods Hole, Massachusetts

3. "Light Conditions in the Sea in Relation to the Diurnal Vertical Migrations of Animals"

   George L. Clarke, Harvard University
   Cambridge, Massachusetts

4. "Photoenvironment nnd the Behavior of Certain Sonic-Scattering Layers"

   Elizabeth M. Kampa
   Scripps Institution of Oceanography
   La Jolla, California

5. "Vertical Migrations of Sonic Scattering Layer Fauna as Related to Bioluminescence"

   Brian P. Boden
   Scripps Institution of Oceanography
   La Jolla, California

6. "Swimbladder Development in Deep-Sea Fishes"

   Normal B. Marshall
   British Museum, London, England

7. "Swimbladder Gas Secretion and Energy Expenditure in Vertically Migrating Fishes"

   R. McN. Alexander
   University of Leeds, Leeds, England

8. "Physiological Constraints on Vertical Migration by Mesopelagic and Bathybenthic Fish"

   Brian G. D'Aoust
   Naval Biological Laboratory
   Oakland, California

9. "Deep Sea Fishes: Lethargy and Vertical Orientation"

Eric G. Barham
Naval Undersea Research and Development Center
San Diego, California

10. "Ocean Acre: Preliminary Report on Vertical Distribution and Biology of Fishes and Cephalopods"

Robert H. Gibbs, Jr. and Clyde F. E. Roper
Smithsonian Institution, Washington, D. C.

11. "Feeding of Zooplankton and Vertical Patterns of Distribution and Migration"

J. E. G. Raymont
University of Southampton
Southampton, England

12. "Microbial Distribution in Ocean Water Relative to Nutrients and Food Sources:

Osmund Holm-Hansen
Scripps Institution of Oceanography
La Jolla, California

13. "Resonant Acoustic Scattering From Gas Bladder Fishes"

William E. Batzler and George V. Pickwell
Naval Undersea Research and Development Center
San Diego, California

14. "Measurements of the Target Strength of Fish in Dorsal Aspect, Including Swimbladder Resonance"

Brian S. McCartney
National Institute of Oceanography
Surrey, England

15. "Sound Extinction by Fish in One-Way Shallow-Water Propagation"

David E. Weston and P. A. Ching
Admiralty Research Laboratory
Middlesex, England

16. "A Statistical Theory of Ocean Reverberation"

David Middleton, Consulting Physicist
Concord, Massachusetts

17. "An Instrument for Measuring Integrated Volume Scattering Strengths"

Paul T. McElroy, Woods Hole Oceanographic Institution
Woods Hole, Massachusetts

18. "Time Variations of Some Acoustic Volume Reverberation Parameters"

Robert L. Swarts, Honeywell Inc.
Seattle, Washington

19. "Geographic, Seasonal and Annual Patterns of Midwater Scatterers Between 10^{o} and 68^{o} North in the Atlantic Ocean"

Kenneth Haigh
Admiralty Underwater Weapons Establishment, Dorset, England

20. "The Deep Scattering Layer: Patterns Across the Gulf Stream and the Sargasso Sea"

Henry P. Cole and George M. Bryan
Geophysics Institute of the University of Alaska, College, Alaska and Lamont-Doherty Geological Observatory Palisades, New York

21. "Quasi-Synoptic Measurements of Volume Reverberation in the Western North Atlantic"

Edward E. Davis
Naval Oceanographic Office
Washington, D. C.

22. "Geographic Variations in the Acoustic Characteristics of Deep Scattering Layers"

Robert P. Chapman, Orest Z. Bluy, and Raymond H. Adlington
Defence Research Establishment Atlantic, Dartmouth, Scotia, Canada

23. "Volume Backscattering Measurements at 12 kHz in the Mediterranean Sea and a Description of a Multiple Frequency Sounder for Further Investigations"

Christian S. Jeannin
Laboratoire de Detection Sous-Marine
Le Brusc (Var), France

24. "The Acoustically Determined Distribution of Resonant Scattering North of Oahu"

Peter Van Schuyler
Naval Oceanographic Office
Washington, D. C.

25. "Biological Results From Scattering Layer Investigations in the Norwegian Sea"

Bernard J. Zahuranec and W. Lawrence Pugh
Naval Oceanographic Office, Washington, D. C.

26. "Scattering Layers and Vertical Distribution of Oceanic Animals Off Oregon"

William G. Pearcy and Roderick S. Mesecar
Oregon State University
Corvallis, Oregon

27. "A Reconnaissance of the Deep Scattering Layers in the Eastern Tropical Pacific and the Gulf of California"

Calvin R. Dunlap, Hopkins Marine Station
Stanford University
Pacific Grove, California

28. "Studies on the Fauna Associated with the Deep Scattering Layers in the Equatorial Indian Ocean"

Margaret G. Bradburn and Donald P. Abbott
San Francisco State College, San Francisco, California and
Horkins Marine Station, Stanford University,
Pacific Grove, California

29. "Correlations Between Surface-Measured Swimbladder Volumes, Depth of Resonance and 12 kHz Echograms at the Time of Capture of Sound Scattering Fishes"

Lloyd W. Shearer
Naval Oceanographic Office
Washington, D. C.

30. "Acoustic Scattering from Zooplanktonic Organisms"

Peter C. Beamish and Edward D. Mitchell
Bedford Institute, Dartmouth, Nova Scotia and
Fisheries Research Board of Canada, Ste. Anne de Bellevue,
Quebec, Canada

31. "The Contribution of Euphausiids and Other Plankton Organisms to Deep Scattering Layers in the Eastern North Atlantic"

Johannes Kinzer
Institut für Hydrobiologie und Fischereiwissenshaft,
Universität Hamburg, Germany

32. "Biological Acoustic Scattering off Southern California, Baja California and Guadalupe Island"

George V. Pickwell, Robert J. Vent, Eric G. Barham and
William E. Batzler
Naval Undersea Research and Development Center
San Diego, California

33. "Biological Causes of Scattering Layers in the Arctic Ocean"

Max J. Dunbar and William J. Hansen
McGill University, Montreal, Canada

34. "Sonic Scattering and its Probable Causes in Two Areas of Puget Sound"

William A. Friedl
Naval Undersea Research and Development Center
San Diego, California

35. "Comparison of Different Investigative Techniques for Studying the Deep Scattering Layers"

William D. Clarke
Westinghouse Laboratories
San Diego, California

36. "The Horizontal Dimensions and Abundance of Fish Schools in the Upper Mixed Layer as Measured by Sonar"

Paul E. Smith
Bureau of Commercial Fisheries
La Jolla, California